New & Recent B-Physics Results on Lifetime and Mixing

P. Gutierrez

gut@fnal.gov

Department of Physics & Astronomy

University of Oklahoma

Outline

Results presented from BaBar, Belle, DØ, CDF, and Delphi

- Lifetime Measurements
  - Overview
  - New lifetime ratios
  - Summary
- Mixing Measurements
  - Overview
  - New B_d mixing measurements
  - New limit on B_s mixing
- $\Delta\Gamma_s/\Gamma_s$ measurement
- Summary

Experimental Overview

- B-Factories (BaBar, Belle)
  - $e^+e^- \rightarrow \Upsilon(4S) \rightarrow b\bar{b}$
  - $\sigma \approx 1$ nb
  - Clean environment
- LEP(Delphi)
  - $e^+e^- \rightarrow Z \rightarrow b\bar{b}$
  - $\sigma \approx 7$ nb
  - Clean environment
  - Access to B_s, B_c, Λ_b, ...
- Tevatron (DØ, CDF)
  - $p\bar{p} \rightarrow b\bar{b} + X$
  - $\sigma \approx 150$ μb @ 1.96 TeV
  - Multiple interactions, hardonic remnants
  - Access to B_s, B_c, Λ_b, ...

Lifetime Measurements—Motivation

- Lifetimes probe QCD at large distances (*bound state*)
- For "*Heavy*" quarks expect lifetime to be dominated by quark
  - Lifetime differences observed in D-mesons
  - b heavier, expect smaller differences $(\tau(B_{q'})/\tau(B_q) \approx 1)$
- Leading OPE terms in Γ for "*heavy*" quark hadron decay:
  - Spectator term
  - Chromomagnetic term $(1/m_Q^2$ suppression)
  - 4-quark interaction term $(1/m_Q^3$ suppression)
- Prediction $\tau(B_u^+) \geq \tau(B_d^0) \approx \tau(B_s^0) > \tau(\Lambda_b) \gg \tau(B_c^+)$
- Experimental numbers given as ratios relative to B_d^0 to reduce systematics

Λ_b *Lifetime*

- New lifetime ratio result from DØ $(250$ pb$^{-1})$

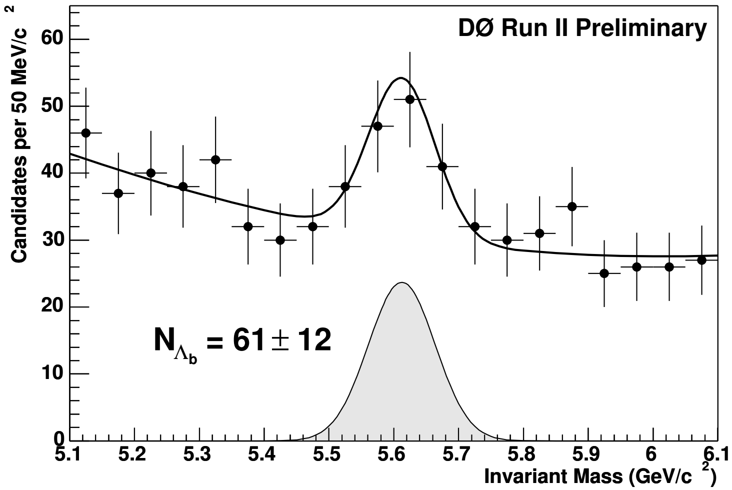
$$\Lambda_b \to J/\psi + \Lambda^0 \to (\mu^+\mu^-) + (p\pi^-)$$

$$B_d^0 \to J/\psi + K_s^0 \to (\mu^+\mu^-) + (\pi^+\pi^-)$$

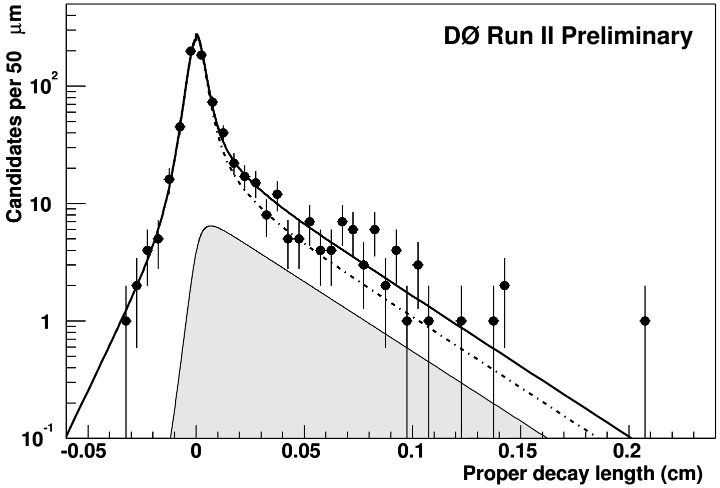
  - Presently theory predicts $\tau(\Lambda_b)/\tau(B_d^0) \approx 0.9 \pm 0.05$ while the world average is 0.798 ± 0.052
  - Previous ratio measurements used semileptonic decays
  - First Λ_b ratio measurement using fully reconstructed decay modes
  - CDF presented Λ_b lifetime measurement earlier this year using $\Lambda_b \to J/\psi + \Lambda^0$

Λ_b *Lifetime*

J/ψ-Λ^0 Mass Distribution



J/ψ-Λ^0 Lifetime Distribution



DØ: $\tau_{\Lambda_b} = 1.221^{+0.217}_{-0.179} \pm 0.043$ ps

CDF: $\tau_{\Lambda_b} = 1.25 \pm 0.26 \pm 0.10$ ps

World Avg: $\tau_{\Lambda_b} = 1.229 \pm 0.080$ ps

DØ: $\tau_{B_d^0} = 1.397^{+0.107}_{-0.098} \pm 0.031$ ps

DØ: $\tau_{\Lambda_b}/\tau_{B_d^0} = 0.874^{+0.169}_{-0.142} \pm 0.028$

Theory: $\tau_{\Lambda_b}/\tau_{B_d^0} = 0.9 \pm 0.05$

World Avg: $\tau_{B_s}/\tau_{B_d^0} = 0.798 \pm 0.052$

B_s **Lifetime**

- New result from DØ on B_s to B_d lifetime ratio

$$B_s^0 \rightarrow J/\psi + \phi \rightarrow (\mu^+\mu^-) + (K^+K^-)$$

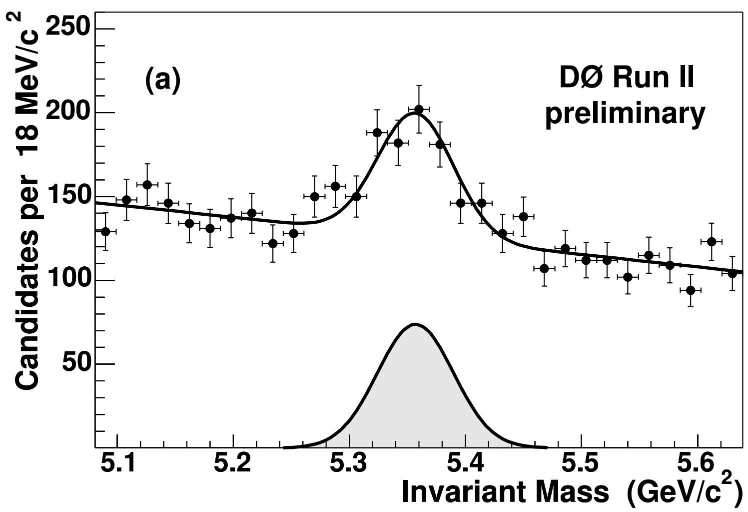
$$B_d^0 \rightarrow J/\psi + K^{*0} \rightarrow (\mu^+\mu^-) + (K^+\pi^-)$$

  - Use fully reconstructed modes to determine ratio
  - Presently theory predicts $\tau(B_s)/\tau(B_d^0) = 1.00 \pm 0.01$ while the world average is 0.951 ± 0.038

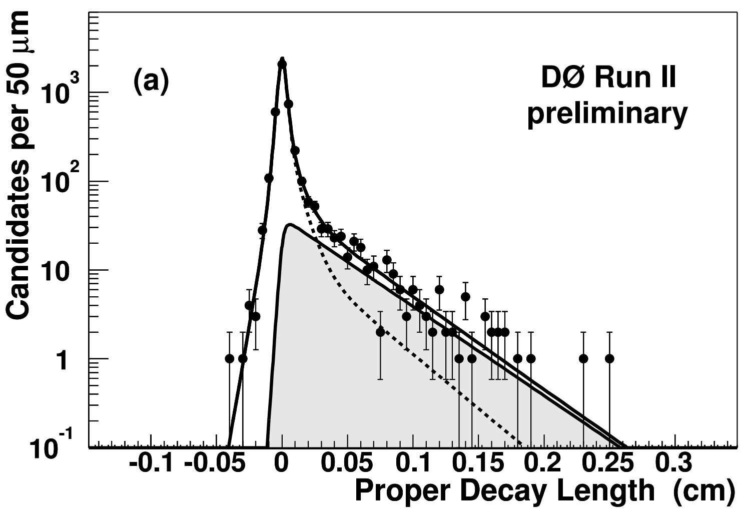
- Recent CDF B_s lifetime measurement using $B_s^0 \rightarrow J/\psi\phi$

B_s ***Lifetime***

J/ψ-ϕ Mass Distribution



J/ψ-ϕ Lifetime Distribution



DØ: $\tau_{B_s} = 1.444^{+0.098}_{-0.090} \pm 0.020$ ps

World Avg: $\tau_{B_s} = 1.229 \pm 0.080$ ps

CDF: $\tau_{B_s} = 1.369 \pm 0.100 \pm^{+0.008}_{-0.010}$ ps

DØ: $\tau_{B_d^0} = 1.473^{+0.052}_{-0.050} \pm 0.023$ ps

Theory: $\tau_{B_s^0}/\tau_{B_d^0} = 1.00 \pm 0.01$

DØ: $\tau_{B_s^0}/\tau_{B_d^0} = 0.980^{+0.075}_{-0.070} \pm 0.003$

World Avg: $\tau_{B_s}/\tau_{B_d^0} = 0.951 \pm 0.038$

B_u^+ Lifetime

- Recent ratio measurements from DELPHI, DØ, and CDF
  - DELPHI uses NN on $Z \rightarrow b\bar{b}$ $(1.060 \pm 0.021 \pm 0.024)$
  - DØ uses $B \rightarrow D^{*-}\mu^+\nu + X$ dominated by $B_d^0(86\%)$ and $B \rightarrow \bar{D}^0\mu^+\nu + X$ dominated by $B_u^+(82\%)$ $(250$ pb$^{-1})$ $(1.093 \pm 0.021 \pm 0.022)$
  - CDF uses $B_d^0 \rightarrow J/\psi + K^{*0}$ and $B_u^+ \rightarrow J/\psi + K^+$ $(250$ pb$^{-1})$ (1.080 ± 0.042)
- New ratio measurement from BELLE $(1.066 \pm 0.008 \pm 0.008)$
  - From CP asymmetry measurement $29.1 \rightarrow 140$ fb^{-1}
- BaBar new B_d^0 lifetime $(1.501 \pm 0.008 \pm 0.030$ ps$)$
- World Average (1.085 ± 0.017) Theory (1.06 ± 0.02)

Mixing—Overview

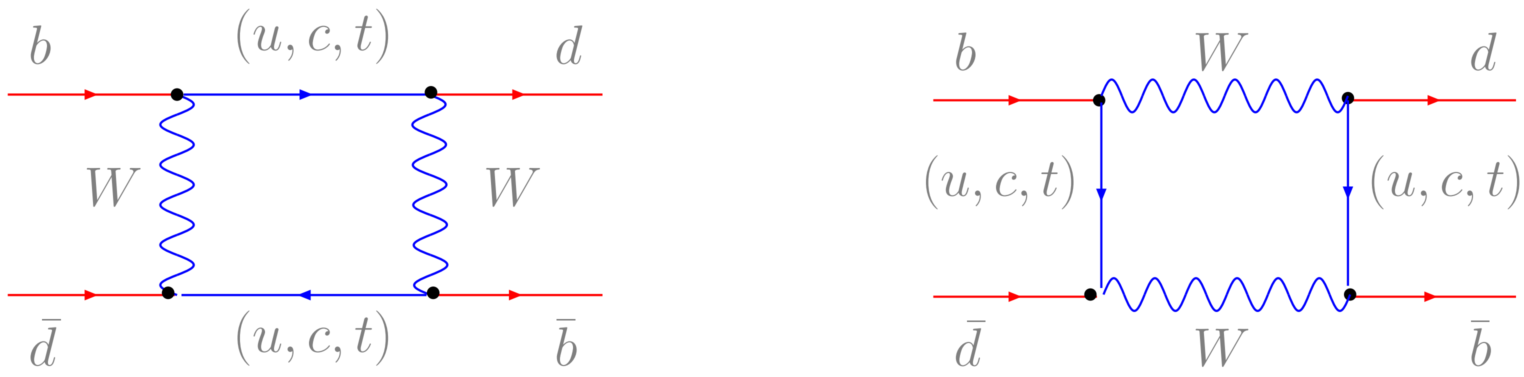
- Since Mass and Flavor eigenstates not equal, flavor states can mix.
  - Requires mass of eigenstates to differ $(\Delta m_q \neq 0)$
  - Mass eigenstates can have different lifetimes $(\Delta\Gamma_q \neq 0)$
  - Standard Model expectation $\Delta m_q \gg \Delta\Gamma_q$

$$\mathcal{P}^{\text{unmixed}}_{\text{mixed}}(t) = \frac{1}{2}\Gamma_q\, e^{-\frac{\Gamma_q}{2}t}\left[\cosh\left(\frac{\Delta\Gamma_q}{2}t\right) \pm \cos\left(\Delta m_q t\right)\right]$$

Where $\Gamma_q = \frac{\Gamma_H + \Gamma_L}{2}$ the average of the decay widths of the two mass eigenstates.

Mixing—Overview

- Mixing requires a $|\Delta B| = 2$ transition ($B^0 \to \bar{B}^0$)



- Amplitude is $\propto |V_{tb}V_{td}|$ because of large t-quark mass
  - Amplitude $\propto \sum_q S_0\left(\frac{m_q}{M_W}\right)$

Mixing—Procedure

- Mixing requires measurement of initial and final flavor
  - Final state tagging examples

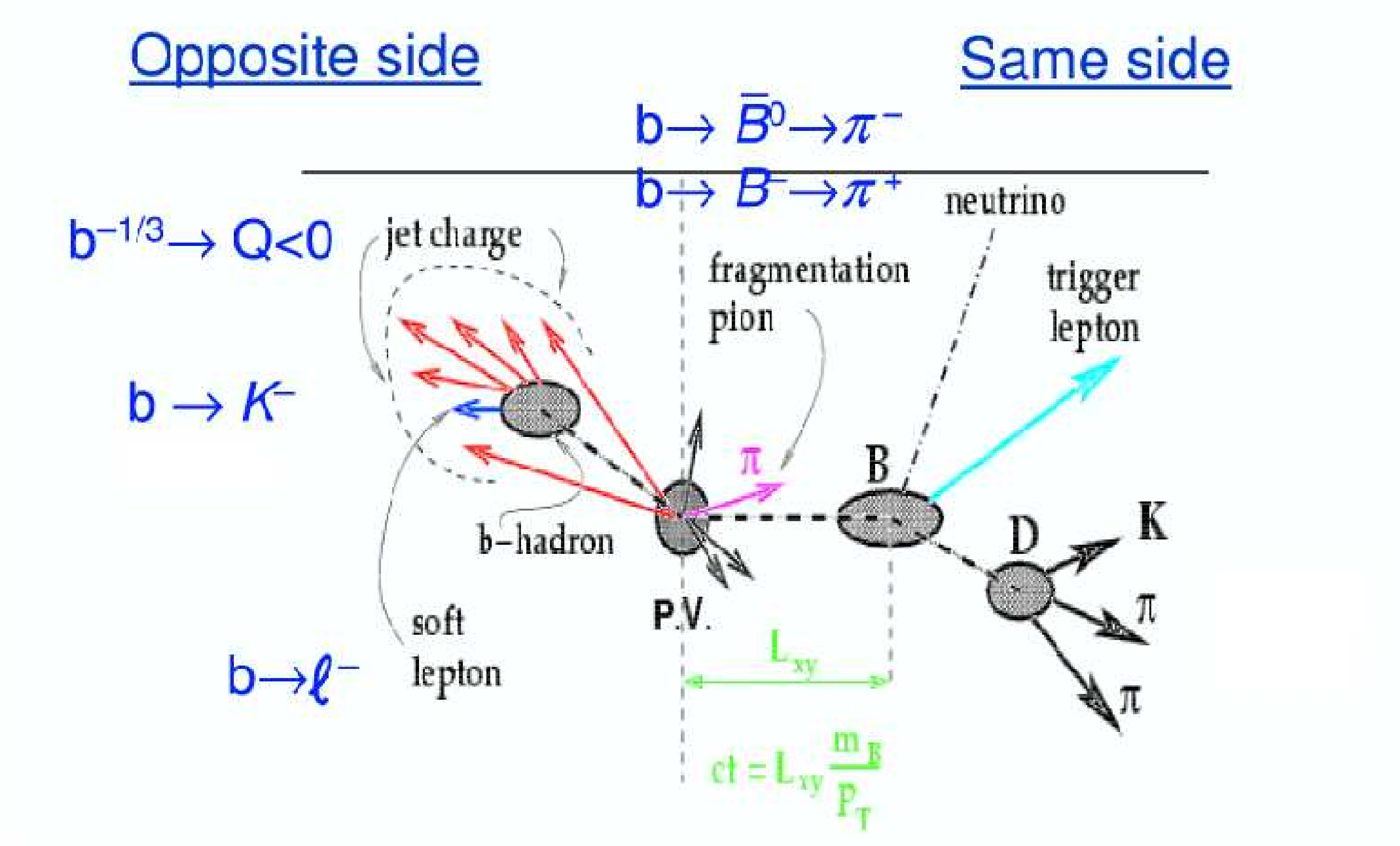
$$B_d^0 \to D^{*-}\mu^+\nu_\mu \qquad\qquad B_d^0 \to J/\psi K^{*+}\pi^-$$

$$\bar{B}_d^0 \to D^{*+}\mu^-\bar{\nu}_\mu \qquad\qquad \bar{B}_d^0 \to J/\psi K^{*-}\pi^+$$

  - $\mu^\pm$ ($\pi^\pm$) provide tag for decay flavor
  - First set not fully reconstructed, $\approx 5.4\%$ branching ratio
  - Second set fully reconstructed, $\approx 8 \times 10^{-4}$ branching ratio

Mixing—Procedure

- Initial state tagging



B_d ***Mixing—Results***

- New result on B_d mixing from DØ & CDF $(\approx 250$ pb$^{-1})$
  - Both use semi-lepton decays: $B^0 \to \bar{D}\ell^+\nu_\ell$
  - Both use Same-Side-Tagging, CDF combines all taggers

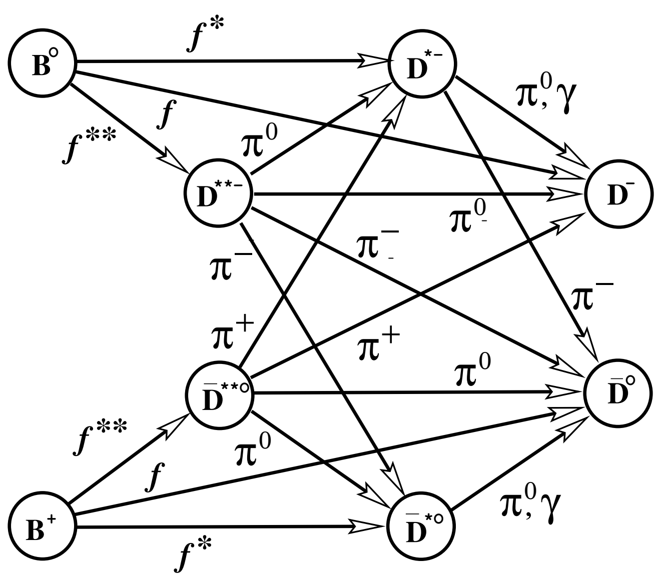
CDF

$$B^0 \to \left\{ \begin{array}{c} D^{*-} \\ D^- \end{array} \right\} \qquad B^+ \to \bar{D}^0$$

DØ

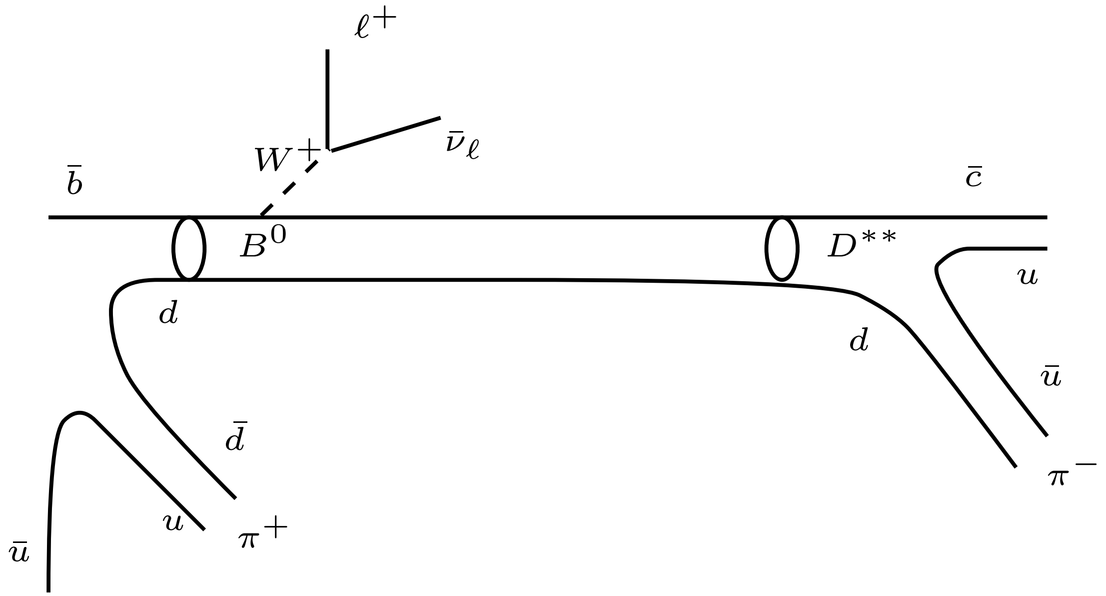
$$B \to \bar{D}^0 \quad \Rightarrow \quad \left\{ \begin{array}{l} B^0 \to D^{*-} \\ B^+ \to \bar{D}^0 \end{array} \right.$$

$B \to D$ Decays

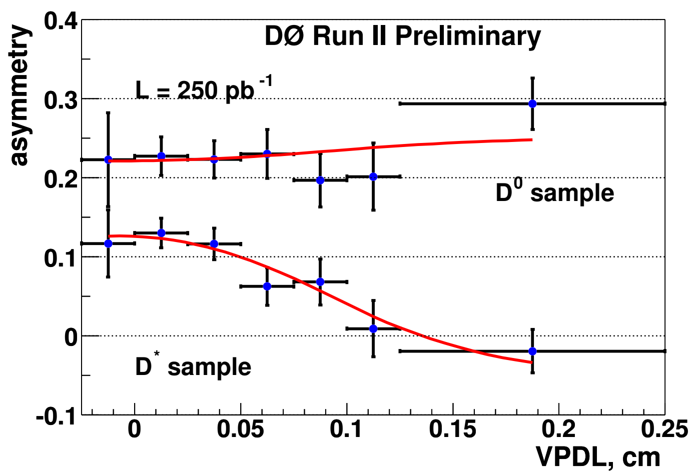


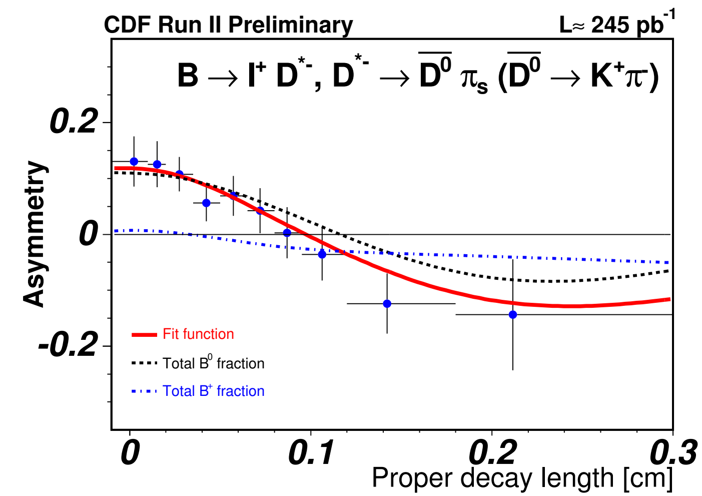
B_d *Mixing—Results*

- Same Side Tagging Algorithm
  - Cone about B-meson $\Delta R = 0.7$
  - Take $\pi^\pm$ with smallest p_T^{rel}
- Main systematic $\pi^\pm$ from D^{**} decay



B_d Mixing—Results





Results

CDF(SST): $\Delta m_d = 0.443 \pm 0.052 \pm 0.030 \pm 0.012$ ps^{-1}

CDF(All): $\Delta m_d = 0.536 \pm 0.037 \pm 0.009 \pm 0.015$ ps^{-1}

DØ(SST): $\Delta m_d = 0.488 \pm 0.066 \pm 0.044$ ps^{-1}

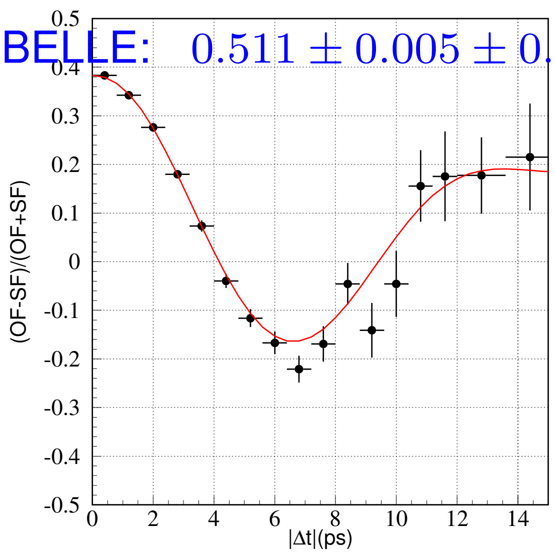
DØ(OμT): $\Delta m_d = 0.506 \pm 0.055 \pm 0.049$ ps^{-1}

PDG: $\Delta m_d = 0.502 \pm 0.007$ ps^{-1}

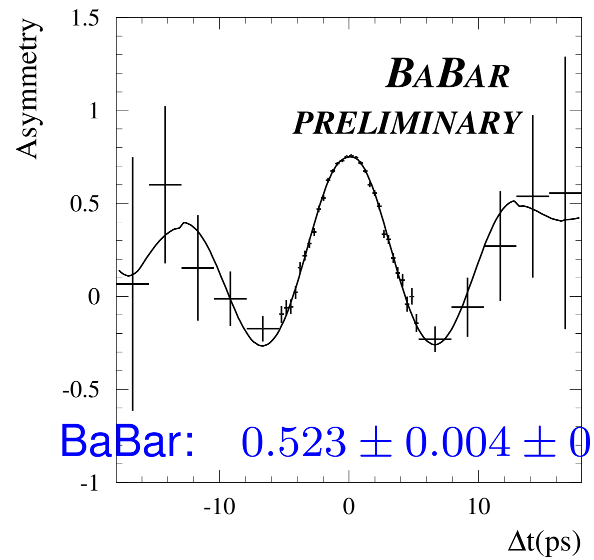
B_d ***Mixing—Results***

- New results from BELLE (*by-product of CP asymmetry measurement*) and BaBar
  - Use $B_d^0 \to D^{*-}\ell^+\nu$ and fully reconstructed hadronic modes   BaBar uses only semi-leptonic mode
  - Flavor tag other B using $\ell^\pm$, $\pi^\pm$ $K^\pm$, Λ_s^0 not associated with reconstructed B BaBar opposite side $\ell^\pm$ only

BELLE: $0.511 \pm 0.005 \pm 0.006$ ps^{-1}



BaBar: $0.523 \pm 0.004 \pm 0.007$ ps^{-1}



B_s Mixing Limit

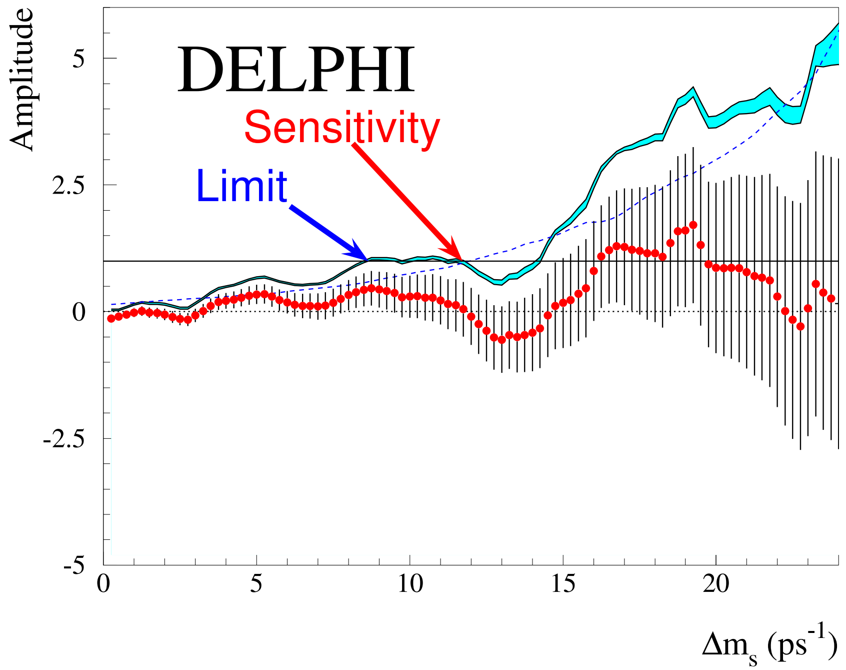
- DELPHI has produced two new limits on B_s mixing
- Mixing limit obtained using “Amplitude” Method
  - Fit data to $\mathcal{P} = \frac{\Gamma}{2} e^{-\Gamma t} \left[1 \pm A \cos(\Delta m_s t)\right]$
  - Fit for A as a function of Δm_s
    - A peaks at 1 for a measurement
    - Sensitivity given by $1.645\sigma_A = 1$ 95% exclusion
    - Limit given by $A < 1 - 1.645\sigma_A$ 95% exclusion

B_s Mixing Limit

- Data samples used for limit
  - $\bar{B}^0_s \to D^+_s \ell^- \nu_\ell + X$ Analysis
    - $D^+_s \ell$ is updated result with improved use of proper time resolution
    - Sensitivity improved from 8.4 ps^{-1} to 8.6 ps^{-1}
  - High p_T Lepton Analysis
    - Event divided into 2 hemispheres by plane Transverse to Sphericity axis
    - Lepton gives decay tag
    - Lifetime from particles in lepton hemisphere
    - Production tag from Opposite Side jet charge NN, plus Same Side kaon combined in a single discriminant

B_s Mixing Limit

Amplitude Plot



Limits 95% CL

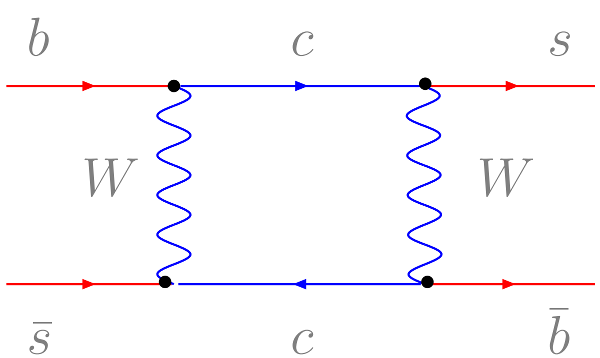
Lepton Analysis:	$\Delta m_s > 8.0(12.0)$ ps^{-1}
$D_s + \ell^{\pm}$ Analysis:	$\Delta m_s > 4.9(8.6)$ ps^{-1}
All Delphi Analysis:	$\Delta m_s > 8.5(12.0)$ ps^{-1}
PDG	$\Delta m_s > 14.4$ ps^{-1}

(Sensitivity)

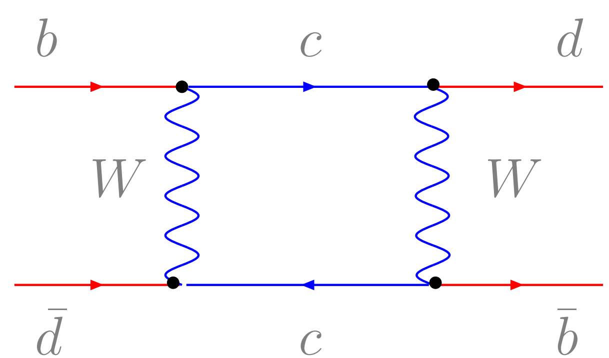
$\Delta\Gamma_s$—*Overview*

- Lifetime of mass eigenstates not expected to be equal
  - $\Delta\Gamma_q/\Gamma_q$ expected to be small, but since $\Delta m_s \gg \Delta m_d$ might expect $\Delta\Gamma_s/\Gamma_s \gg \Delta\Gamma_d/\Gamma_d$
    - $\Delta\Gamma_d/\Gamma_d \approx 0.01$ $\quad\quad$ $\Delta\Gamma_s/\Gamma_s = 0.12 \pm 0.06$ Niertse, . . . `hep-ph/0012219`
    - Cabbibo allowed $b \to c \to s$ transition for B_s while Cabbibo suppressed $b \to c \to d$ for B_d

$B_s \to \bar{B}_s$



$B_d \to \bar{B}_d$



$\Delta\Gamma_s$—*Analysis*

- Must separate out two mass eigenstates
  - These are the CP even and odd states

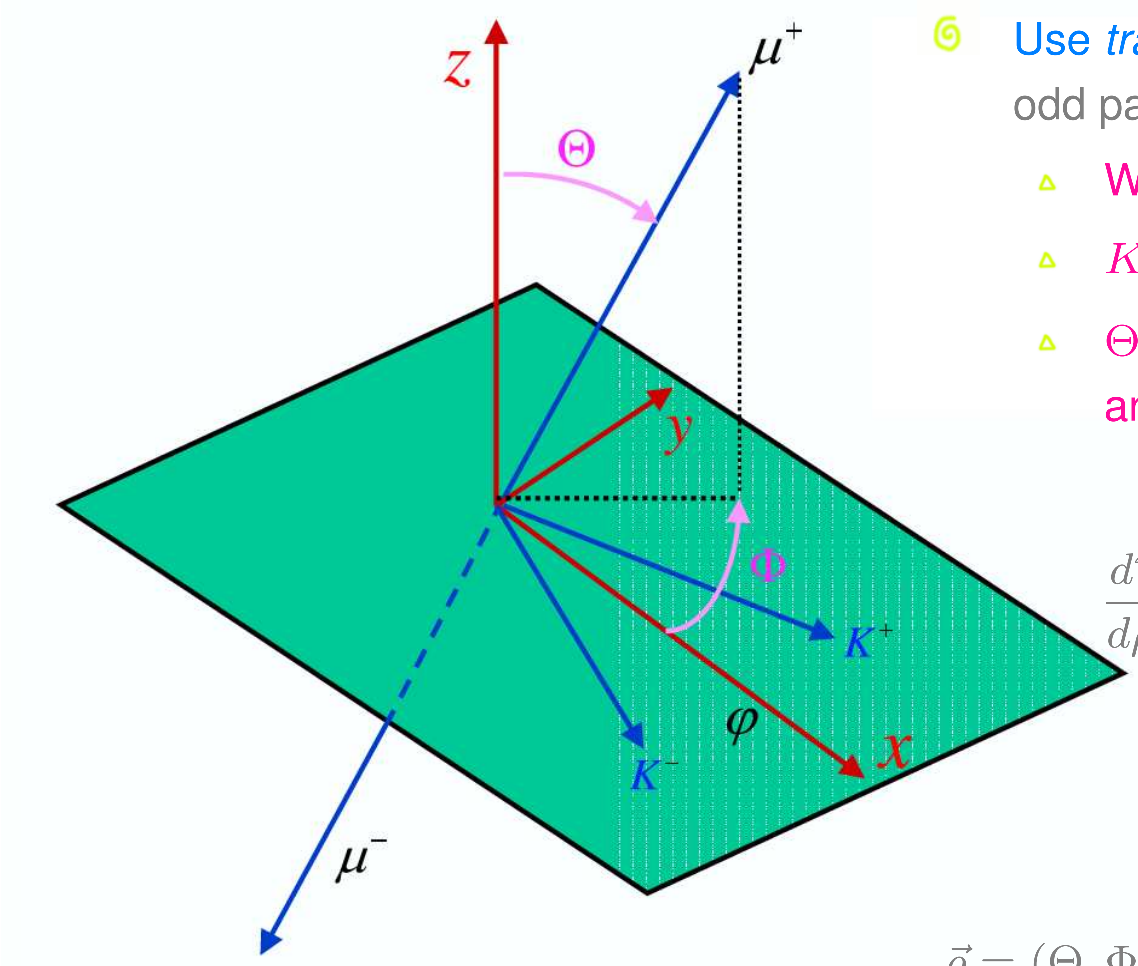
$$B_s^H = \frac{1}{\sqrt{2}} \left[|B_s\rangle + |B_s\rangle \right] \qquad CP \text{ odd}$$

$$B_s^L = \frac{1}{\sqrt{2}} \left[|B_s\rangle - |B_s\rangle \right] \qquad CP \text{ even}$$

  - Use $B_s \to J/\psi\phi$ w/final state $J = 0$ since J/ψ & ϕ have $S = 1$ this $\Rightarrow \ell = 0, 1, 2$ (S, P, D wave)
  - S & $D \Rightarrow CP$ even
  - $P \Rightarrow CP$ odd
- **Goal is to disentangle different ℓ states**

$\Delta\Gamma_s$ ***Analysis***

Transversity Angles



- Use $B_s \to J/\psi\phi$ ($B_d \to J/\psi K^{0*}$)
- Use *transversity* angles—Separates odd parity states nicely
  - Work in J/ψ rest frame
  - K^+K^- defines x-y plane
  - Θ, Φ are μ^+ polar, azimuthal angles, Ψ helicity angle of ϕ

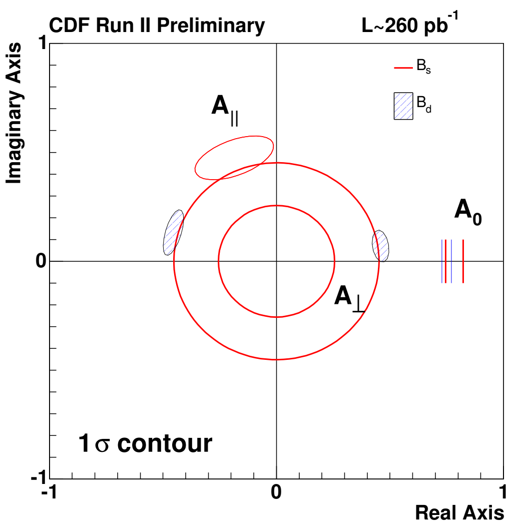
Angular Distribution B_s

$$\frac{d^4\mathcal{P}}{d\vec{\rho}dt} \propto |A_0|^2 f_1(\vec{\rho})e^{-\Gamma_L t} + |A_\parallel|^2 f_2(\vec{\rho})e^{-\Gamma_L t} + |A_\perp|^2 f_3(\vec{\rho})e^{-\Gamma_H t} + \mathrm{Re}(A_0^* A_\perp) f_5(\vec{\rho})e^{-\Gamma_L t}$$

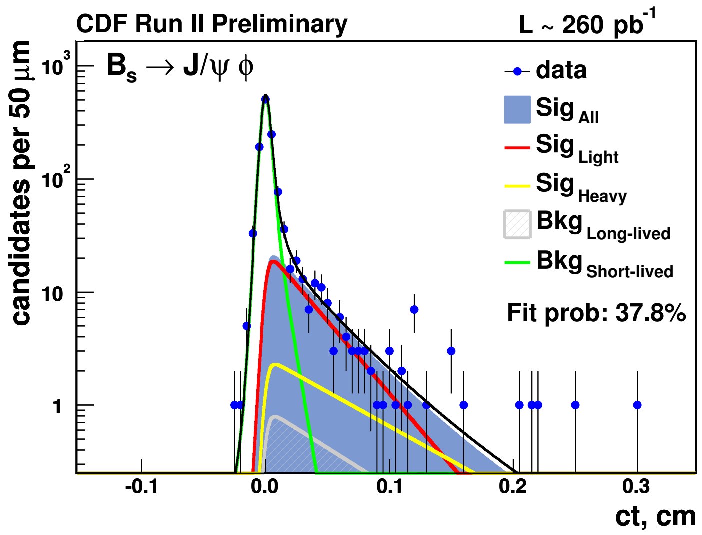
$\vec{\rho} = (\Theta, \Phi, \Psi)$

$\Delta\Gamma_s$ *Analysis*

Amplitudes



Lifetime



Results

$A_0 = 0.784 \pm 0.039 \pm 0.007$

$A_{||} = (0.510 \pm 0.082 \pm 0.013)e^{(1.94\pm0.36\pm0.03)i}$

$|A_\perp| = 0.354 \pm 0.098 \pm 0.003$

$\Delta\Gamma_s/\Gamma_s = 0.65^{+0.25}_{-0.33} \pm 0.01$

$\Delta\Gamma_s = 0.47^{+0.19}_{-0.24} \pm 0.01$ ps^{-1}

$\tau_L = 1.05^{+0.16}_{-0.13} \pm 0.02$ ps

$\tau_H = 2.07^{+0.58}_{-0.46} \pm 0.03$ ps

Summary

- New lifetime ratio measurements for B_u^+, B_s^0 and Λ_b vs. B_d^0 from BELLE, CDF, and DØ
  - New DØ $\tau(\Lambda_b)/\tau(B_d^0)$ measurement consistent with theory, higher than world average
- New measurements of Δm_d
  - For Tevatron, starting point for measurement of Δm_s
- New Δm_s limit from DELPHI
- CDF measures $\Delta\Gamma_s/\Gamma_s$